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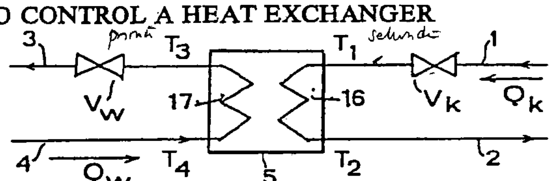

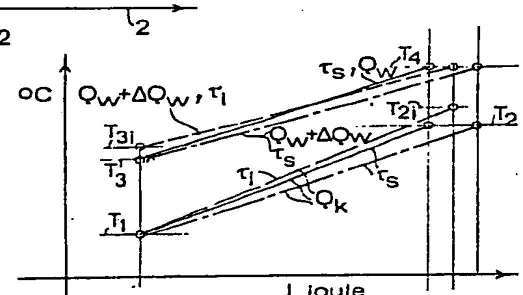

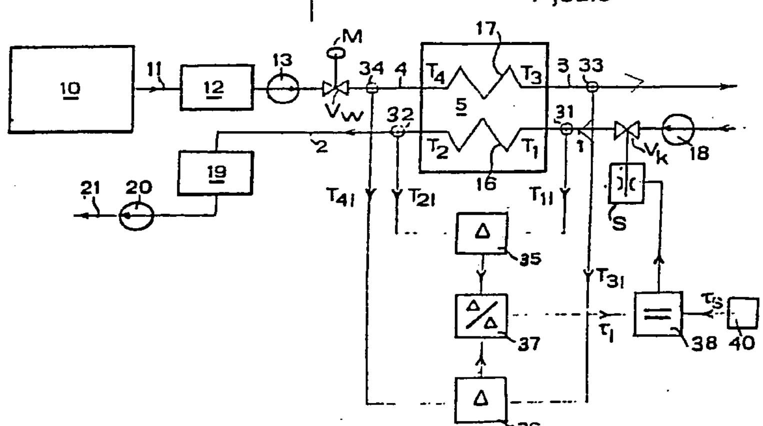

(57) Abstract

A method of controlling flows of heat donating fluid (Q_W) having the inlet temperature T_4 and the outlet temperature T_3 and a heat accepting fluid (Q_k) having the inlet temperature T_1 and the outlet temperature T_2 through a heat exchanger (5) so that the relation between the enthalpy efficiency ne and the temperature efficiency n_T of the heat exchanger is maintained at a predetermined desired value t_s, by measuring the momentary inlet temperatures T_{1i} and T_{4i}, respectively, and outlet temperatures T_{2i} and T_{3i}, respectively, of the two fluids, forming the quotient $(T_{4i}-T_{3i})/(T_{2i}-T_{1i})$ and using this quotient as a desired value t_i for controlling either flow (Q_W or Q_k) by comparison between the value of the quotient t_i and the predetermined desired value t_s. A device for executing the method comprises temperature sensors (31, 34 and 33, 32, respectively) arranged in the inlets (1, 4) and outlets (2, 3) of the two fluids, the signals of said temperature sensors being applied to differentiating units (35, 36), one for the temperatures of each fluid, the output signals of the two differentiating units are applied to a quotient unit (37), said unit generating an output signal t_i, which is applied to a comparing unit (38) comparing the output signal (t_i) of the quotient unit with a signal (t_s) representing the predetermined desired value (t_s) and generates a control signal for a servo unit (S) actuating a valve (V_k or V_W) controlling the flow in the flow path of one of the fluids.

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METHOD AND DEVICE TO CONTROL A HEAT EXCHANGER

The present invention relates to a method of controlling the flows of fluids flowing through a heat exchanger, to maintain the efficiency of the heat exchanger at a predetermined value, selected with respect to the prevailing operational conditions, this method eliminating the necessity of measuring anyone of the flows even if the flow of one of the fluid varies with time. The invention is, as well, in respect of a device for executing the method.

In a great number of industrial processes, large flows of fluid of elevated temperature, such as heated waste water, appear, the flow of said fluid possibly being exposed to large variations in time. In case the temperature level of the fluid being rather high, it may be attractive to recover as much as possible of the heat content of the fluid by conducting it through a heat exchanger preferably a counter current heat exchanger, and there transfer the heat to other fluid making it possible to utilize the heat thus absorbed. However, should the flow of one of said fluids vary, the flow of the other fluid has to be adapted thereto for keeping, within a wide range of operation, the heat exchange in the heast exchanger at or near to an optimal value with respect to prevailing operational conditions.

The solution to this problem which seems nearest at hand and is commonly used implies a direct fluid measurement and controlling the flow of one of the fluids in dependence of the flow of the second fluid and further measured parameters. However, the direct measuring of flow implies technical as well as economical problems with the magnitudes of flows which may be present in, for instance, a heat exchanger for recovering heat from waste water in an industrial plant.

It is an object of the present invention to substantially eliminate the problems mentioned above by presenting a method of controlling the fluid flow through a heat exchanger in such a manner that the operation of the heat exchanger is maintained substantially at an optimal level even with variations in the flow of one of the fluids, the controlling of the flow of the second fluid being provided for without the use of a direct flow measurement.

According to the invention this object is achieved by making use of a method having characteristics as appearing from the appended claims, which are as well in respect of a device for executing the method.

In the following, the invention will be more closely described with reference to the accompanying drawing, in which:

Fig. 1 schematically shows a heat exchanger with pertaining fluid flow parameters,

Fig. 2 is a diagram illustrating the relation between the temperature and enthalpy levels of the fluids flowing through the heat exchanger, and

Fig. 3 schematically illustrates an application of the method according to the invention.

Fig. 1 shows a heat exchanger 5, which may, for instance, be a heat exchanger for recovering heat from large flows of water at elevated temperature, often waste water, and transfer of such heat to a second flow of water. The heat exchanger has an inlet 1 for "cold" water to be heated and flowing with a flow Q_k through the heat exchanger to an outlet 2, and an inlet 4 for "warm" water, from which heat is to be transferred to the cold water and which, with a flow Q_w, flows to an outlet 3. The temperatures at the connections of the heat exchanger, that is, the inlets and the outlets, are, respectively, at the inlet 4 T_4 at the inlet 3 T_3, at the inlet 1 T_1 and at the outlet 2 T_2. As most often preferred, the heat exchanger operates in counter current.

Fig. 2 shows diagrammatically the progress of temperature, ^oC, and enthalpy, I, in the two flows, the flow Q_w being cooled down from T_4 to T_3, while the flow Q_k is heated from T_1 to T_2.

The parameter of interest for the heat exchanger, which, according to the invention, is to be kept at a predetermined wanted value to maintain a substantially optimal utilization of the heat exchanger, is a temperature relation T_s which can be written as:

$$r_s = \frac{T_4 - T_3}{T_2 - T_1}$$

For deducing this parameter as a basis for the control of one of the flow quantities in dependence of the size of the other flow quantity so that a transfer of heat from the warner fluid will proceed while maintaining such flow data that the heat exchange within the heat exchanger is maintained substantially optimal for a prevailing purpose, for which the cold fluid is to be used, taking into account the capacity and other properties of the heast exchanger, the following two concepts have been basic. One concept is the "temperature efficiency" of the heat exchanger, defined as:

$$n_T = \frac{T_2 - T_1}{T_4 - T_1}$$

and the second concept the "enthalpy efficiency" of the heat exchanger, defined as

$$n_e = \frac{T_4 - T_3}{T_4 - T_1}$$

where T_1, T_2, T_3 och T_4 are the temperatures as mentioned above. If one considers limiting cases of n_T and n_e during operation of a particular heat exchanger, starting, for instance, from a specific flow of hot waste water, the heat of which has to be recovered, entering the heat exchanger with the temperature T_4, the following will be valid with respect to the cold water entering the exchanger. If the cold water flow Q_k approaches 0, the temperature T_2 thereof when leaving the heast exchanger will approach the inlet temperature T_4 of the hot waste water, that is, the "temperature efficiency" approaches the value 1. At the same time the exit temperature of the waste water approaches its inlet temperature T_3, that is, the "enthalpy efficiency" and therewith the recovery of heat approaches 0.

If, on the contrary, the cold water flow Q_k approaches values which are "too high" for the situation in question with respect to the properties of the heat exchanger, the temperature T_2 as well as the temperature T_3 approaches the inlet temperature T_1 of the cold water, the n_T---0 and n_e---1, implying that the heat "recovery" approaches the value 1 and, at the same time, the temperature increase of the cold water approaches the value 0°C, implying a maximal increase of entropy.

An optimal utilization of the heat exchanger for a prevailing purpose obviously implies that the temperature efficiency n_T as well as the enthalpy efficiency n_e have values deviating from 0. However, these two efficiencies are in such relation to each other that the quotient between them is:

$$\frac{n_e}{n_T} = \frac{T_4 - T_3}{T_2 - T_1},$$

this expression thus corresponding to a progress of the relation n_e/n_T which between the extreme values 0 and 1 for n_e and, correspondingly, 1 and 0 for n_T varies continuously from 0 to infinity, and, consequently, contains the above-mentioned value t_s, being the parameter which according to what has been said above shall be maintained at a predetermined wanted value for a maximal utilization of the heat exchanger in question for a prevailing demand.

Presuming that in Fig. 2 the continuous lines show a situation, in which the condition for an optimal exchange in the heat exchanger prevails and in which, thus, $(T_4-T_3)/(T_2-T_1) = t_s$. The ratio between the flow of the heat donating fluid and the flow of the heat receiving fluid is always, neglecting external losses, $Q_k\ (T_2-T_1) = Q_W\ (T_4-T_3)$. If now the flow of the heat donating fluid is being increased by opertional reasons, the flow of the heat receiving fluid should be increased in a corresponding degree to maintain the predetermined optimal utilization for the purpose in question. With an unaltered flow of the heat receiving fluid and an increase of the flow of the heat donating fluid, the exit temperatures of the two flows would change in accordance with

$$Q_k(T_{2i}-T_1) = (Q_W+\ Q_W)(T_4-T_{3i}),$$

in which Q_W is the change of the flow of the heat donating fluid and T_{3i} and T_{2i}, respectively, are the then prevailing exit temperatures. It is true that the heat recovery is then increased, but the temperature change ratio will be deviating from the predetermined one for obtaining an optimal operation in the relation $t_i/t_s = Q_W/(Q_W+\ Q_W)$. In Fig. 2 this sitution is illustrated by the dashed lines between the temperature levels T_4 and T_{3i} and the temperature levels T_1 and T_{2i}, respectively. After a control of the flow of the heat receiving fluid in accordance with the invention, so that the temperature relation t_i agrees with the predetermined value t_s, a situation illustrated by the dashed-and-dotted lines in Fig. 2 will be present with flow quantities corresponding to the relation $t_s = (Q_W+\ Q_W)/(Q_k+\ Q_k)$, Q_k being the increase of the flow of the heat receiving fluid provided for to reinstall the prescribed parameter in question.

Hence, it is possible to control anyone of the flows in dependence of the other in such a manner that t_s is maintained at a constant level, the measured values T_{1i}, T_{2i}, T_{3i} and T_{4i} of the four temperatures in question are used as primary control signals. Of these primary control signals, the signals representing T_{3i} and T_{4i} are connected to a differentiating unit, generating a signal representing the temperature difference $(T_{4i}-T_{3i})$ and the signals representing T_{1i} and T_{2i} a second differentiating unit generating a signal representing the temperature difference $(T_{2i}-T_{1i})$. Said two signals are applied as input signals to a quotient unit, the output signal of which is representative of the quotient $(T_{4i}-T_{3i})/(T_{2i}-T_{1i})$, said output signal being applied as an input signal representative of the actual value t_i of the present temperature quotient t_s for comparison with the predetermined desired temperature quotient in a comparator unit, the output signal of which constituting an actuating error signal for controlling either of the flows, Q_W

or Q_k, in dependence of the other while maintaining the predetermined parameter of interest for the heat exchanger in question.

It may be emphasized that it is, obviously, inessential whether, at a comparison in the comparating unit, the temperature difference quotients t_s and t_i or the reciprocal values thereof are used for the flow control. No knowledge whatsoever of intensities of flow of the two fluids will be necessary to control the flows such that the quotient between them is maintained constant and at a value corresponding to a predetermined optimal utilization of the heat exchanger. An optimal utilization of the heat exchanger to fulfil a prevailing demand may vary from one operational situation to another, which may then be provided for by selectively changing the signal applied to the comparing unit as a predetermined desired value.

Fig. 3 schematically illustrates an embodiment of a plant for using the control method according to the invention. The details of the plant corresponding to details of Fig. 1 have the same reference numerals as in Fig. 1. Thus, 5 is a heat exchanger, in which flows of a hot water source and from a cold water source are to be mutually controlled according to the invention while heat is transferred from the first-mentioned flow to the last-mentioned one. The heat exchanger 5 has an inlet 4 for water which is hot at said inlet and which when flowing through a channel 16 in the heat exchanger to an outlet 3 donates heat to cold water entering the inlet 1 therefor of the heat exchanger, and which after having passed a channel 17 leaves the heat exchanger at an outlet 2 for said water.

In fig. 3 the block 10 is an industry process equipment from which heated waste water flows out at a varying quantity and/or with varying temperature through a waste water duct 11. For equalization purposes said water flows to a buffer tank 12, which may be desirable or necessary from an economic point of view to equalize heavy variations of the waste water flow or to provide for a possibility to operate the heat exchanger in such a manner that the heat transport from hot waste water to cold fresh water in the heat exchanger can proceed substantially independent of variations in the outflow of waste water from the process equipment of the plant.

From the buffer tank 12 the hot waste water is brought by a pump 13 through a valve V_w and the channel 17 of the heat exchanger to the outlet 3 for the cooled down waste water, to be brought further to waste or purification and possible re-use. In the case as illustrated, the valve V_w is assumed to be controlled after demand, that is, set for a particular constant or quasiconstant waste water flow through the heat exchanger, the flow of the fresh water to be heated in the heat exchanger having to be controlled

according to the invention without a necessity for measuring the size of either one of the flows to maintain a desired operating situation.

Fresh water to be heated is admitted to the fresh water channel 16 of the heat exchanger at its inlet 1 and leaves the heat exchanger at its outlet 2, as shown to a buffer tank 19 for heated fresh water, from which it may be conveyed to user by a pump 20 through a duct 21. Obviously, a need for a buffer tank 19 for heated fresh water may not be present in case the demand of the plant for hot fresh water is always above the quantity hot fresh water obtainable from the heat exchanger when controlled according to the invention for optimal operation.

In the embodiment according to Fig. 3, a control valve V_k is arranged in the fresh water duct to control according to the invention the fresh water flow through the heat exchanger.

To control this valve V_k, water temperature sensors 31-34 are present in the in- and outlets 1-4 of the channels 16 and 17 of the heat exchanger. Of these temperature sensors, the temperature sensor 31 in the fresh water inlet 1 and the temperature sensor 32 in the fresh water outlet 2 are connected to a differentiating unit 35 for transfer thereto of each one signal representative of the actual output values T_{2i} and T_{1i}, respectively, said differentiating unit 35 presenting at its output a signal representative of the difference between said temperatures to a quotient unit 37. Correspondingly, the temperature sensor 33 in the outlet 3 of the waste water and the temperature sensor 34 in the inlet 4 of the waste water are connected to each one input of a differentiating unit 36, the output of which is connected to a second input of the quotient unit 37, the quotient unit 37 at its output presenting a signal representative of the quotient $(T_{4i}-T_{3i})/(T_{2i}-T_{1i})$, that is, the actual output value t_i, to one input of a comparing unit 38, a second input of which receives a signal from an adjustable signal generator 40, a signal representative of the desired value t_s of the temperature relation in question.

In a manner well known per se in connection with servo controls, the comparator 38 generates an actuating error signal, by differentiating, for instance, to control a servo system S for setting the valve V_k, said servo in dependence of a present actuating error signal adjusting the valve position so that the parameter t_s, which is predetermined with respect to the intended operational conditions of the heat exchanger, is maintained, in the case illustrated by Fig. 3, with a quastistationary waste water flow symbolized with a control wheel M, without a necessity for actually measuring either one of the actual sizes of the flows.

In case the operational conditions are such that it might be more

convenient to control the fresh water flow quasistationary or in dependence of a varying demand, the valve V_W may instead be controlled in analogy with the control of the valve V_K as shown in Fig. 3, to maintain the temperature relation t_S.

CLAIMS

1. A method of controlling the flow intensity of a heat donating fluid (Q_W) having the inlet temperature T_4 and the outlet temperature T_3 and a heat receiving fluid (Q_k) having the inlet temperature T_1 and the outlet temperature T_2 flowing through a heat exchanger (5) so that the relation between the enthalpy efficiency n_e and the temperature efficiency n_T of the heat exchanger is maintained at a predetermined desired value t_s, **characterized in that** the momentary inlet temperatures T_{1i} and T_{4i}, respectively, and outlet temperatures T_{2i} and T_{3i}, respectively, are measured, that the quotient $(T_{4i}-T_{3i})/(T_{2i}-T_{1i})$ is formed and used to control the flow of either one of the fluids as an actual value t_i in a comparison with said predetermined desired value t_s by controlling a control means for said fluid to a flow at which the actual value t_i substantially agrees with the predetermined desired value t_s.

2. A device for executing the method according to claim 1 to control the flows of heat donating fluid (Q_W) having the inlet temperature T_4 and the outlet temperature T_3 and a heat receiving fluid (Q_k) having the inlet temperature T_1 and the outlet temperature T_2 flowing through a heat exchanger (5) so that the relation between the enthalpy efficiency n_e and the temperature efficiency n_T of the heat exchanger is maintained at a predetermined desired value t_s, **characterized by** comprising temperature sensors (33, 34 and 31, 32, respectively) in the inlet (4) and the outlet (3) of the heat donating fluid and in the inlet (1) and outlet (2) of the heat receiving fluid (Q_k), said temperature sensors being arranged to present primary control signals (T_{3i}, T_{4i}, T_{1i} and T_{2i}, respectively) representative of the water temperatures at the respective inlets and outlets, a first differentiating unit (36) for generating a signal representative of the difference between the inlet temperature (T_{4i}) and outlet temperature (T_{3i}) and a second differentiating unit (35) for generating a signal representative of the difference between the outlet temperature (T_{2i}) and inlet temperature (T_{1i}) of the heat receiving fluid (Q_k), a quotient unit (37) receiving as input signals the output signals of the two differentiating units (35 and 36) and arranged for generating an output signal (t_i) representative of the ratio between the signals applied to the quotient unit from said two differentiating units (35, 36), a means (40) for generating a signal representative of a predetermined, selected desired value (t_s) for the ratio between the enthalpy efficiency (n_e) and temperature efficiency (n_T) of the heat exchanger, a comparing unit (38) for comparing the output signal (t_i) of said quotient unit (37) and the output signal (t_s) of the means (40) generating said desired value (t_s) and generating an output signal

representative of a difference between said signals, as well as a valve (V_k or V_w) arranged in either one flow path of said fluids to be controlled by a servo unit (S) said servo unit being controlled in dependence of the output signal from the comparating unit (38) to set the valve for delivering a flow of the fluid controlled thereby that the actual value (t_i) substantially agrees with the predetermined desired value (t_s).

3. A device according to claim 2, **characterized by** comprising a buffer tank (12) in a duct from a source (10) of the heat donating fluid (Q_w) to the heat exchanger, said tank being arranged for collecting heat donating fluid from said source and delivering said fluid to the heat exchanger, making possible a transfer of the fluid from the buffer tank to the heat exchanger with a flow deviating from the flow to the buffer tank from said source.

4. A device according to anyone of claims 2 and 3, **characterized by** comprising a buffer tank (19) arranged in a duct from the outlet (2) of the heat accepting fluid (Q_k) from the heat exchanger (5) to a consumer (20, 21), said tank making possible a flow of heat accepting fluid to a consumer deviating from the flow of said fluid from the heat exchanger to the buffer tank.

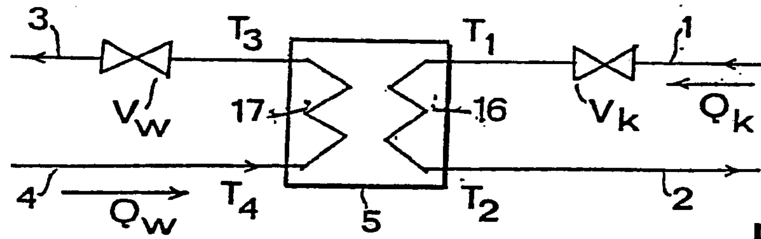

Fig.1

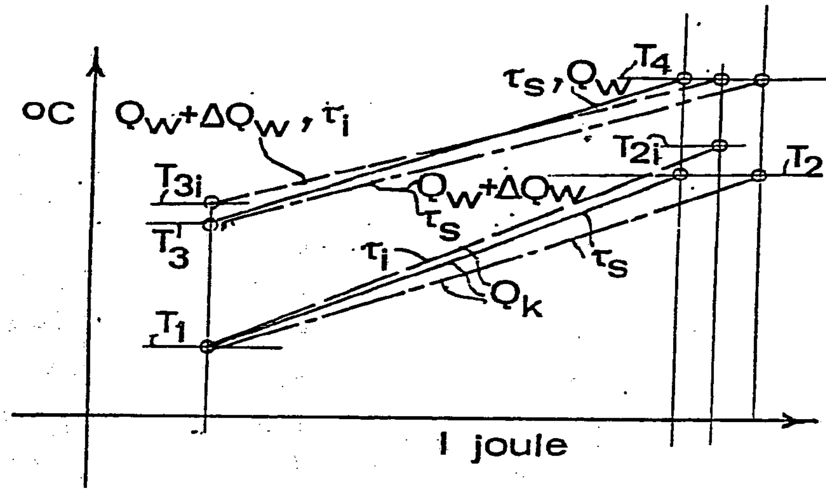

Fig.2

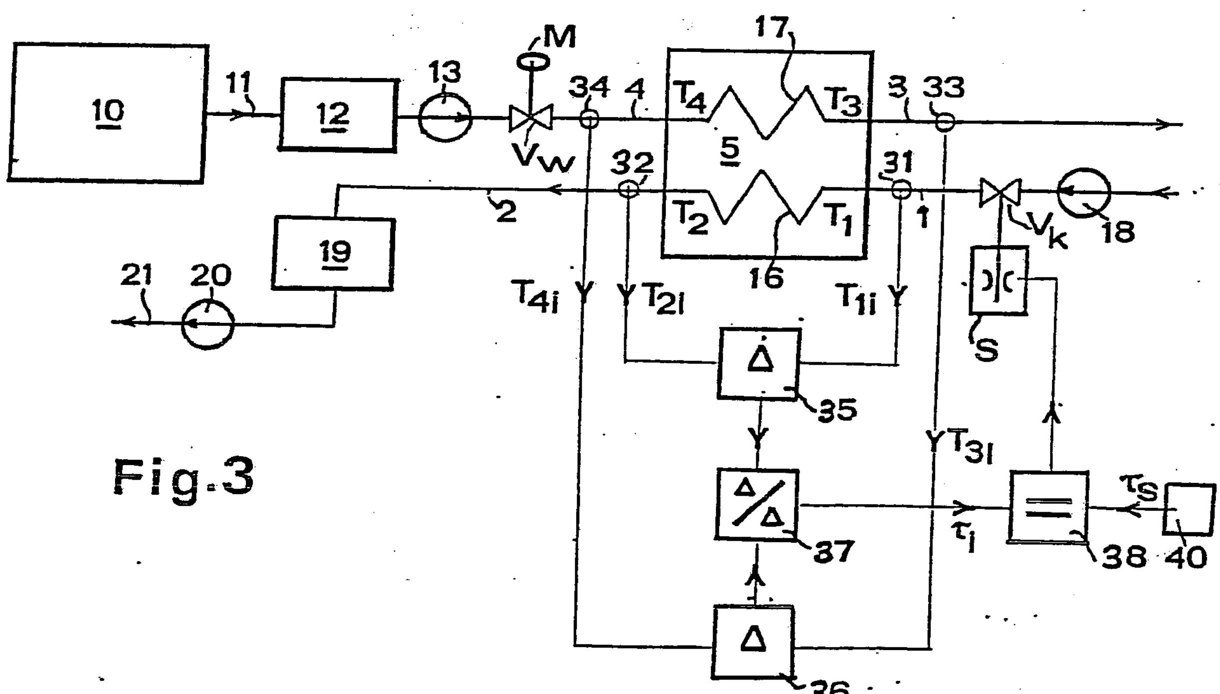

Fig.3

INTERNATIONAL SEARCH REPORT

International Application No PCT/SE81/00256

I. CLASSIFICATION OF SUBJECT MATTER (if several classification symbols apply, indicate all) [3]

According to International Patent Classification (IPC) or to both National Classification and IPC3

F 28 F 27/00, G 05 D 23/00

II. FIELDS SEARCHED

Minimum Documentation Searched [4]

Classification System	Classification Symbols
IPC 3	F 28 F 27/00, G 05 D 23/00,12,19,20,30,32,F 24 D 3/00,10
National Cl	17f:12/01, 12/07
US Cl	73:112; 165:13,14,32,39,40

Documentation Searched other than Minimum Documentation to the Extent that such Documents are Included in the Fields Searched [5]

SE, NO, DK, FI classes as above

III. DOCUMENTS CONSIDERED TO BE RELEVANT [14]

Category *	Citation of Document, [16] with indication, where appropriate, of the relevant passages [17]	Relevant to Claim No. [18]
Y	US, A, 3 918 300 (WEISSTUCH ET AL.) 11 November 1975 (11.11.75)	1
A	DE, A, 2 024 158 (GEBRÜDER SULZER AG) 2 September 1971 (2.09.71)	

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IV. CERTIFICATION

Date of the Actual Completion of the International Search [2]	Date of Mailing of this International Search Report [2]
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Swedish Patent Office	Lars-Erik Strandén

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